The Productivity J-Curve: How Intangibles Complement General Purpose Technologies

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The Modern Productivity Paradox

Our earlier work explored explanations for a paradox:

- Broad optimism about potential of AI and associated technologies

  vs.

- Poor measured productivity performance in the data

Our proposed resolution: implementation lags

- Need to a) accumulate sufficient stocks of new capital and b) invent/install complementary innovations
- These processes can take decades

Slowdowns and GPTs in History

“Engels’ pause” during early industrial revolution

- Wage growth stagnant even as output rose quickly

Only half of U.S. mfg establishments electrified in 1919

- 30 years after AC systems standardized

Computer capital in U.S. didn’t reach long-run level until late 1980s

- 25+ years after invention of integrated circuit
- Only half that level 10 years earlier

Additional Potential Reason for the Paradox

This study explores another reason why productivity slowdowns might accompany new technologies: mismeasurement from GPT-related intangible capital

We theoretically characterize this using growth accounting

Empirically estimate effects from past GPTs (computer software and hardware) and, more speculatively, AI

Intangibles and Productivity Measurement

How do intangibles affect productivity measurement?

$$Productivity = \frac{Output}{Input}$$

- Intangible capital would be an unmeasured input
  - This will cause productivity to be overstated
- But intangible capital investment also an output
  - This will cause productivity to be understated
- Net effect on productivity measurement depends on relative timing of input vs. output mismeasurement

The J-Curve

We show actual minus true productivity growth ($g_{TFP} - \widetilde{g_{TFP}}$) equals weighted difference between growth rates of intangible investment (g_I) and installed intangible capital stock (g_K):

$$g_{TFP} - \widetilde{g_{TFP}} = \sum \left(\frac{\lambda}{z} - 1 \right) \frac{zI}{Y} (g_I - g_K)$$

- Summation is over (possibly) multiple intangible types
- λ / z is intangible's market value relative to purchase price
- zI/Y is intangible investment as share of output
- $g_I - g_K$ is difference between investment and stock growth

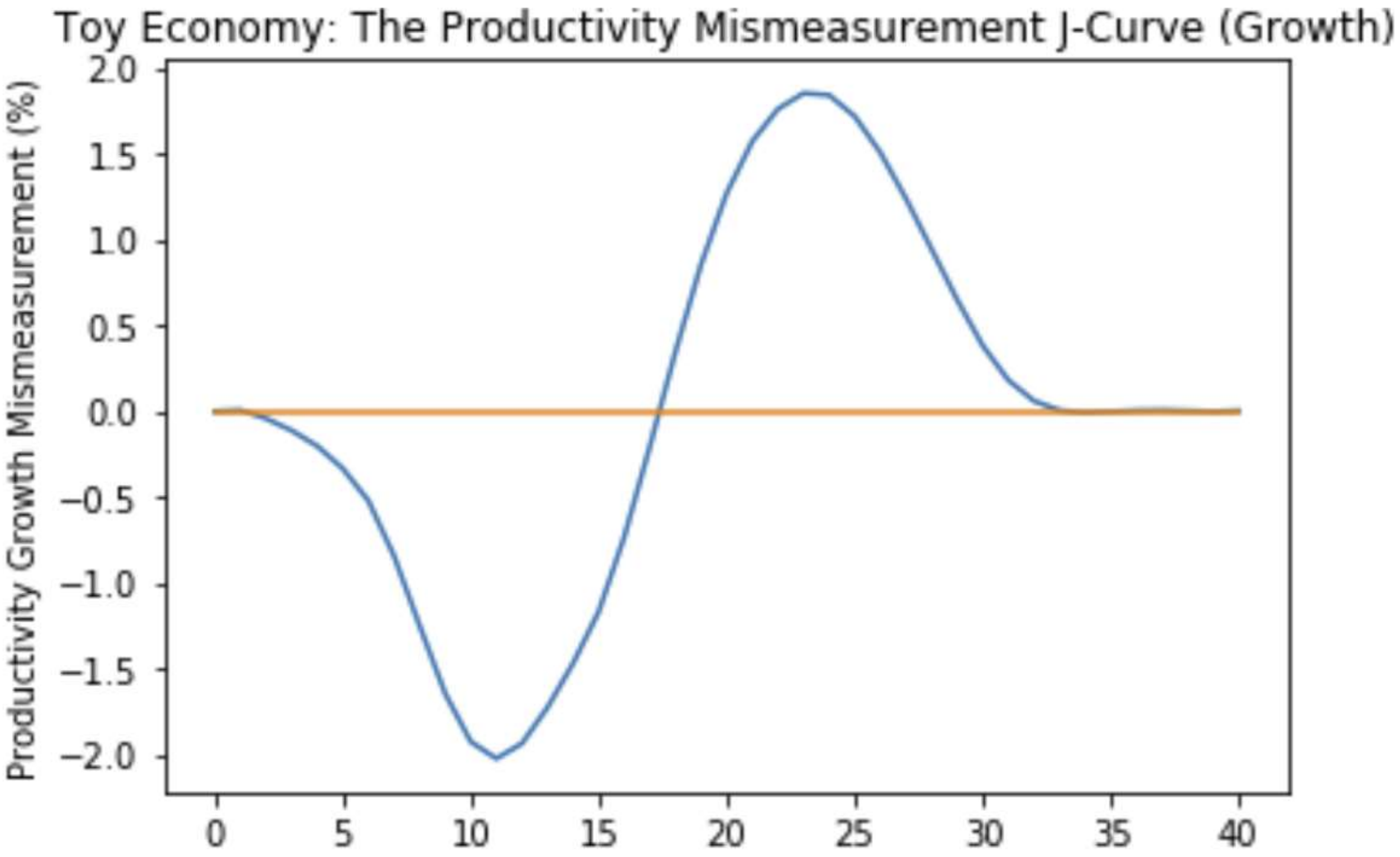
The J-Curve

$$g_{TFP} - \widetilde{g_{TFP}} = \left(\frac{\lambda}{z} - 1\right)\frac{zI}{Y}(g_I - g_K)$$

How might we expect mismeasurement to evolve (assuming $\lambda > z$)?

- Early in a GPT diffusion process, g_I likely larger than g_K, so true productivity growth higher than measured
- Later, g_I falls while g_K stays steady or rises; true productivity growth lower than measured
- Eventually, in steady state, $g_I = g_K$; no mismeasurement (even as intangible investment continues)

The J-Curve



Toy Economy: The Productivity Mismeasurement J-Curve (Growth)
Productivity Growth Mismeasurement (%)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
5
10
15
20
25
30
35
40

Empirical Strategy

Obviously, key element is the amount of intangible capital

How to measure intangibles?

- Suppose two types of K, tangible (*j* = 1) and intangible (*j* = 2)
- Firm makes intangible investments that accompany tangible investments, so that $K_2(t) = \mu K_1(t)$
- Firm's market value is then

$$V = \lambda_1 K_1 + \lambda_2 K_2 = \lambda_1 K_1 + \lambda_2 \mu K_1 = (\lambda_1 + \lambda_2 \mu) K_1$$

- Thus regression of firm market value on tangible capital gives insight into stock and shadow value of intangible capital

Empirical Strategy

Measure λ/z using firm value regressions

For different types of capital with $\lambda > z$, use estimates to construct measure of $g_{TFP} - \widetilde{g_{TFP}}$

Integrate to find implied difference in TFP levels

Firm Value Regressions: R&D

Table 1: Market Value Regressions on R&D and SG&A Stocks

Market Value Regressions (1962-2017)	(1) Basic R&D	(2) Basic R&D and SG&A	(3) Industry-Year Fixed Effects: R&D	(4) Industry-Year Fixed Effects: R&D and SG&A	(5) Firm and Year Fixed Effects: R&D	(6) Firm and Year Fixed Effects: R&D and SG&A
Total Assets	1.016	0.998	1.015	0.999	1.013	0.997
	(0.00179)	(0.00232)	(0.00853)	(0.0107)	(0.00725)	(0.0110)
R&D Stock	2.730	1.753	2.841	1.953	2.161	1.509
	(0.105)	(0.0970)	(0.479)	(0.399)	(0.297)	(0.278)
SG&A Stock		1.755		1.657		1.453
		(0.102)		(0.399)		(0.374)
Constant	656.8	458.7				
	(14.32)	(18.06)				
Firm-Year Observations	268,687	268,687	266,795	266,795	267,683	267,683
R-squared	0.987	0.988	0.989	0.989	0.993	0.993
Industry-Year FE	No	No	Yes	Yes	No	No
Firm and Year FE	No	No	No	No	Yes	Yes

Robust standard errors in parentheses

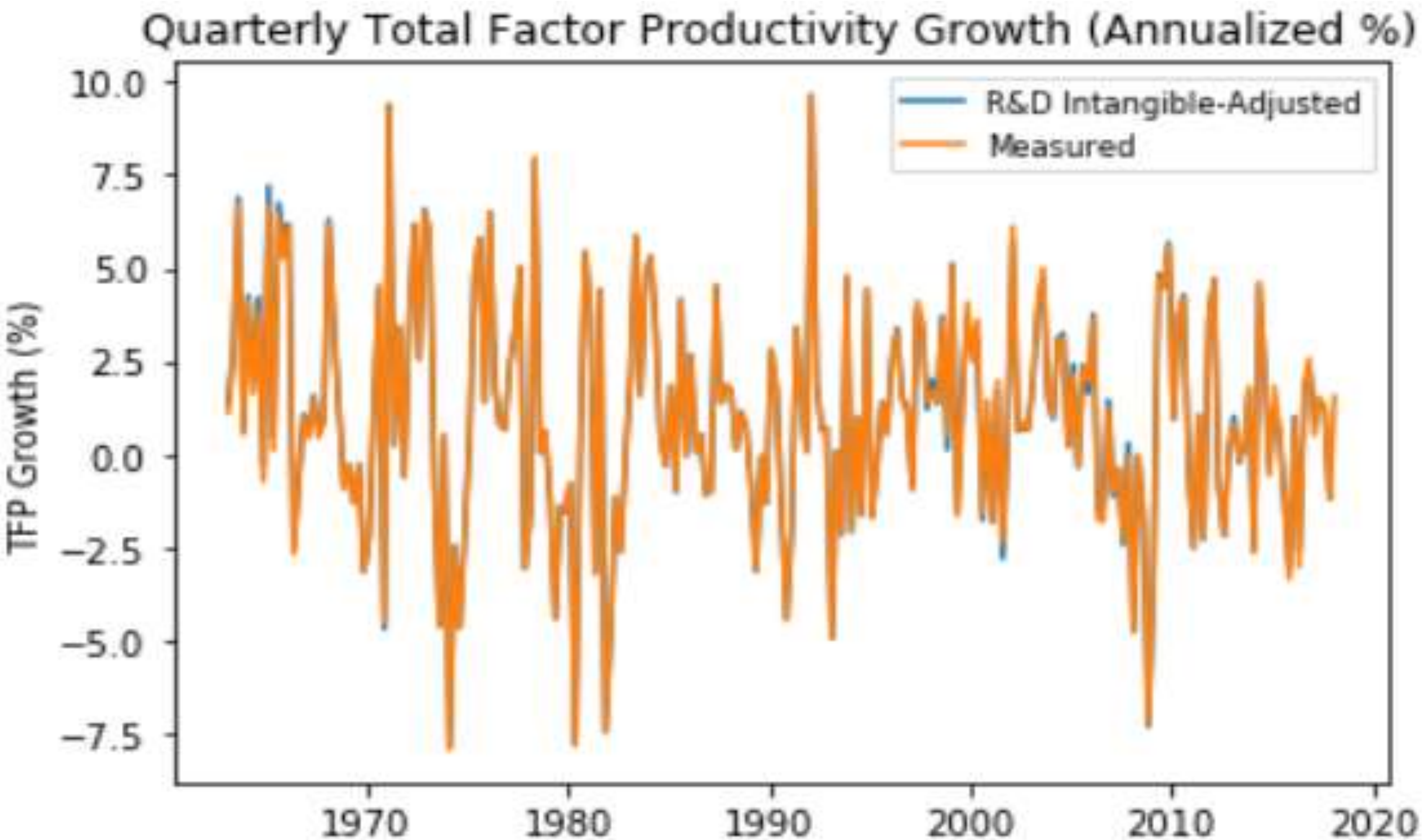
Firm Value Regressions: R&D

Tangible "standard" capital appears to be valued dollar-for-dollar, both across companies and within companies over time

OTOH, $1 of R&D appears to be associated with $2 of shadow value, so perhaps $1 dollar of intangibles per $1 R&D

SG&A proxy for intangibles captures some of this, but also seems to be correlated with shadow value above $1

Measured and Adjusted TFP Growth: R&D



Adjusted TFP: R&D

Why is mismeasurement so small if for every dollar of R&D there is an implied additional $1 of intangible capital?

Because R&D investment rates have been stable for decades

Thus $g_I \approx g_K$

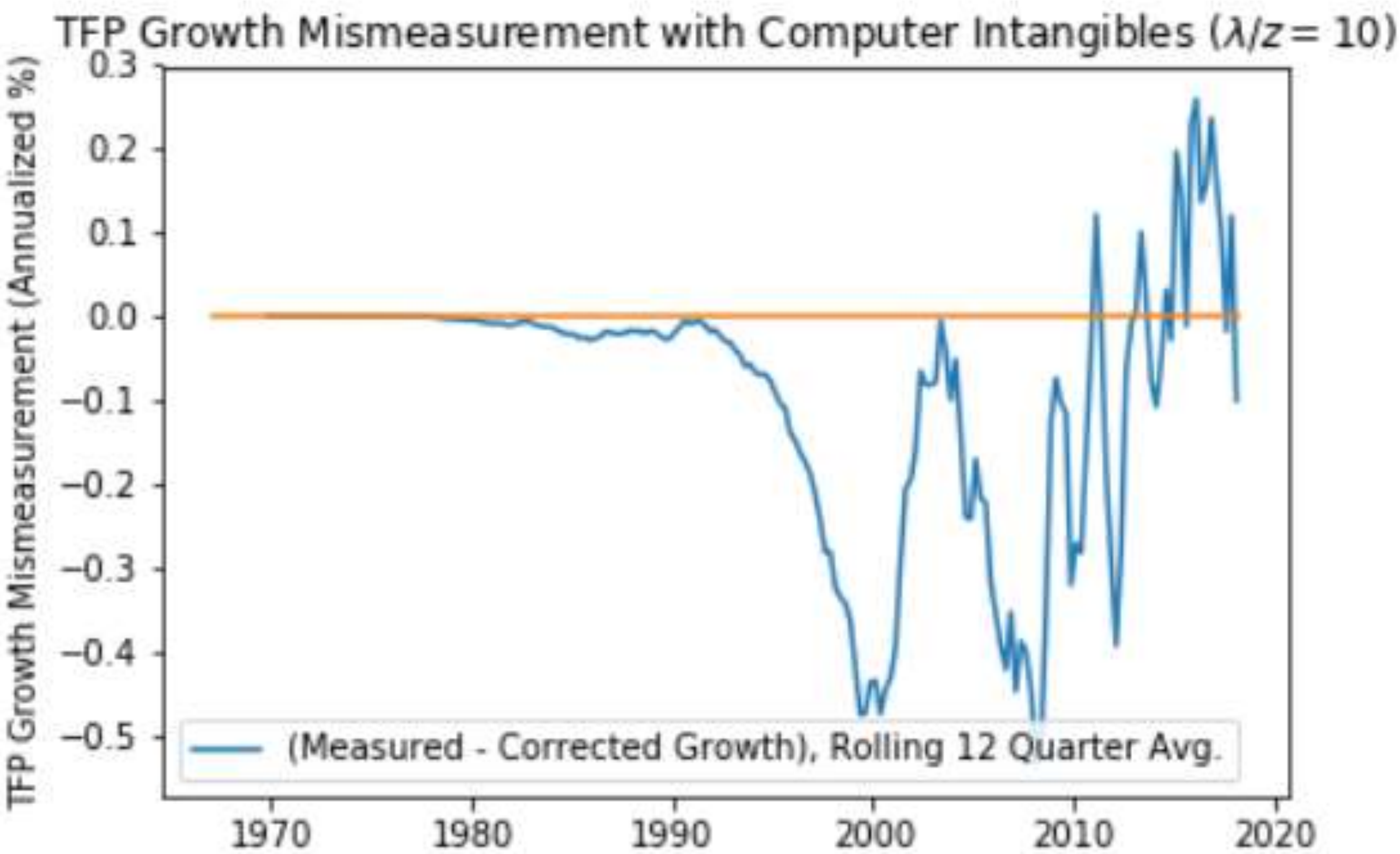
Firm Values: Hardware and Software

We don’t have firm-level IT capital data as we did for R&D

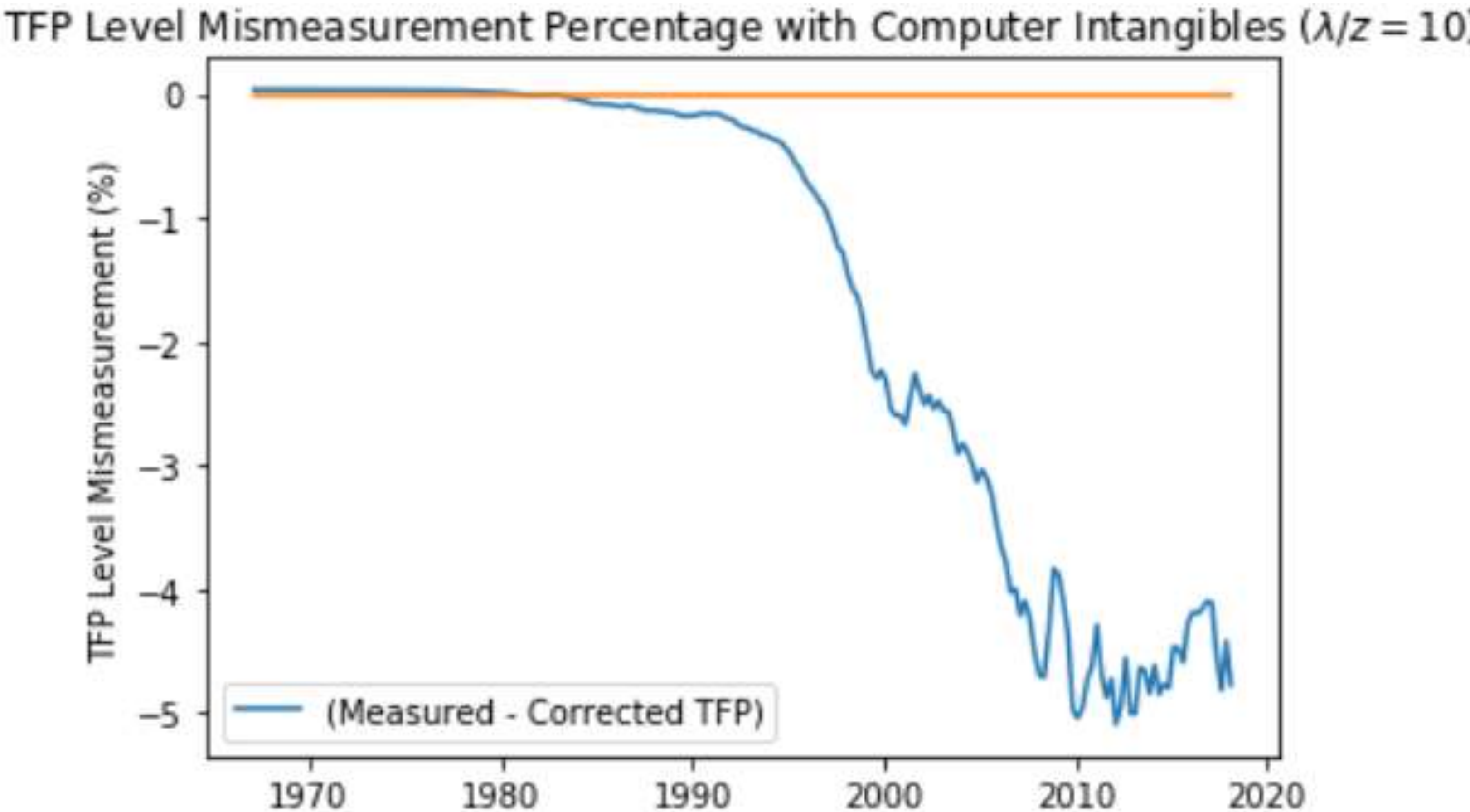
We instead proceed by computing implied mismeasurement for different values of λ/z based on the literature

- Brynjolfsson, Hitt, and Yang (2002) estimate $1 of computer hardware and software associated with about $12 (s.e. = $4) of market value
- We use λ/z of $10; results change proportionately for alternative values of $5, $3, and $2

TFP Growth Mismeasurement by Year: IT Hardware



TFP Accumulated Level Mismeasurement: IT Hardware

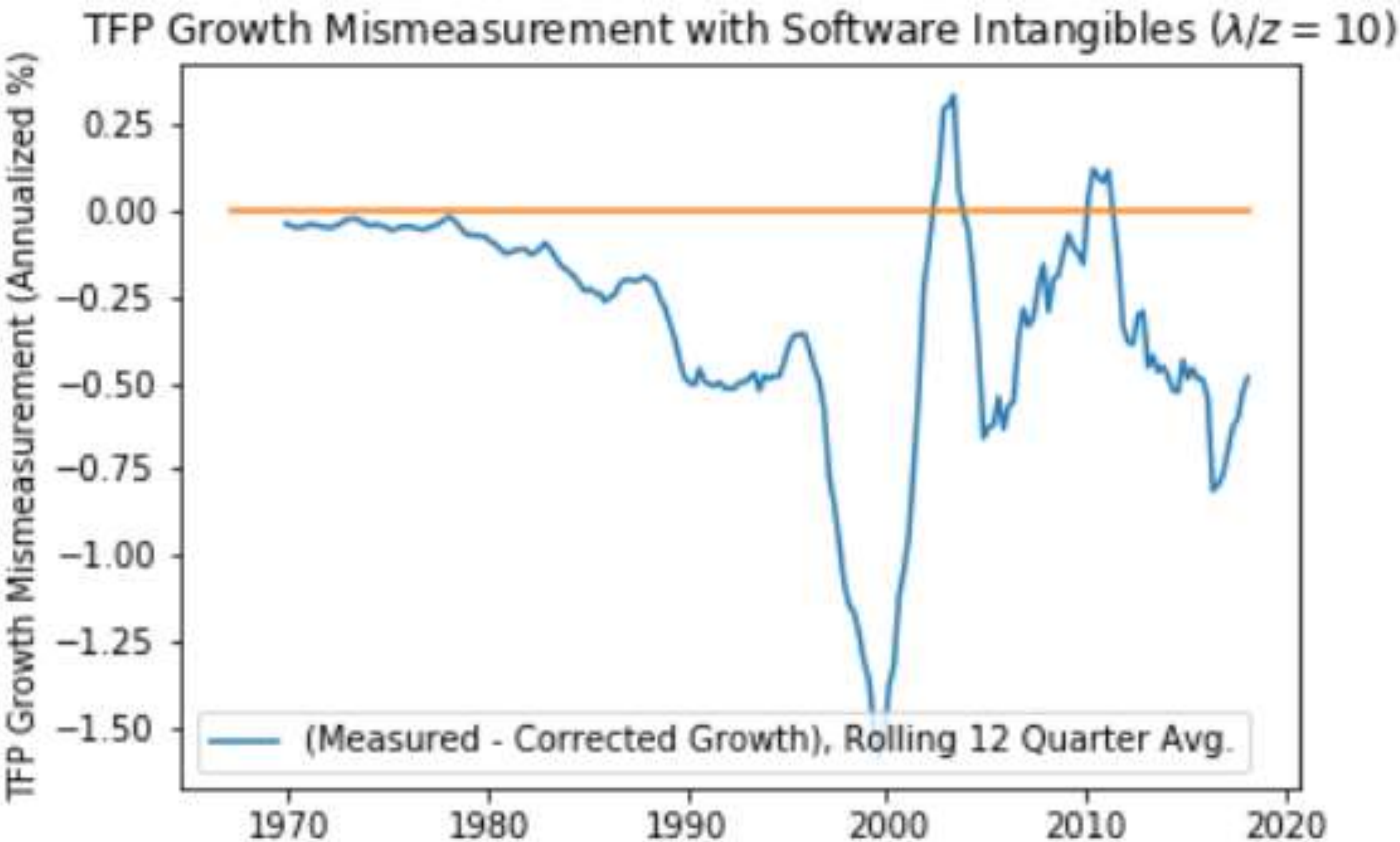


Adjusted TFP: IT Hardware

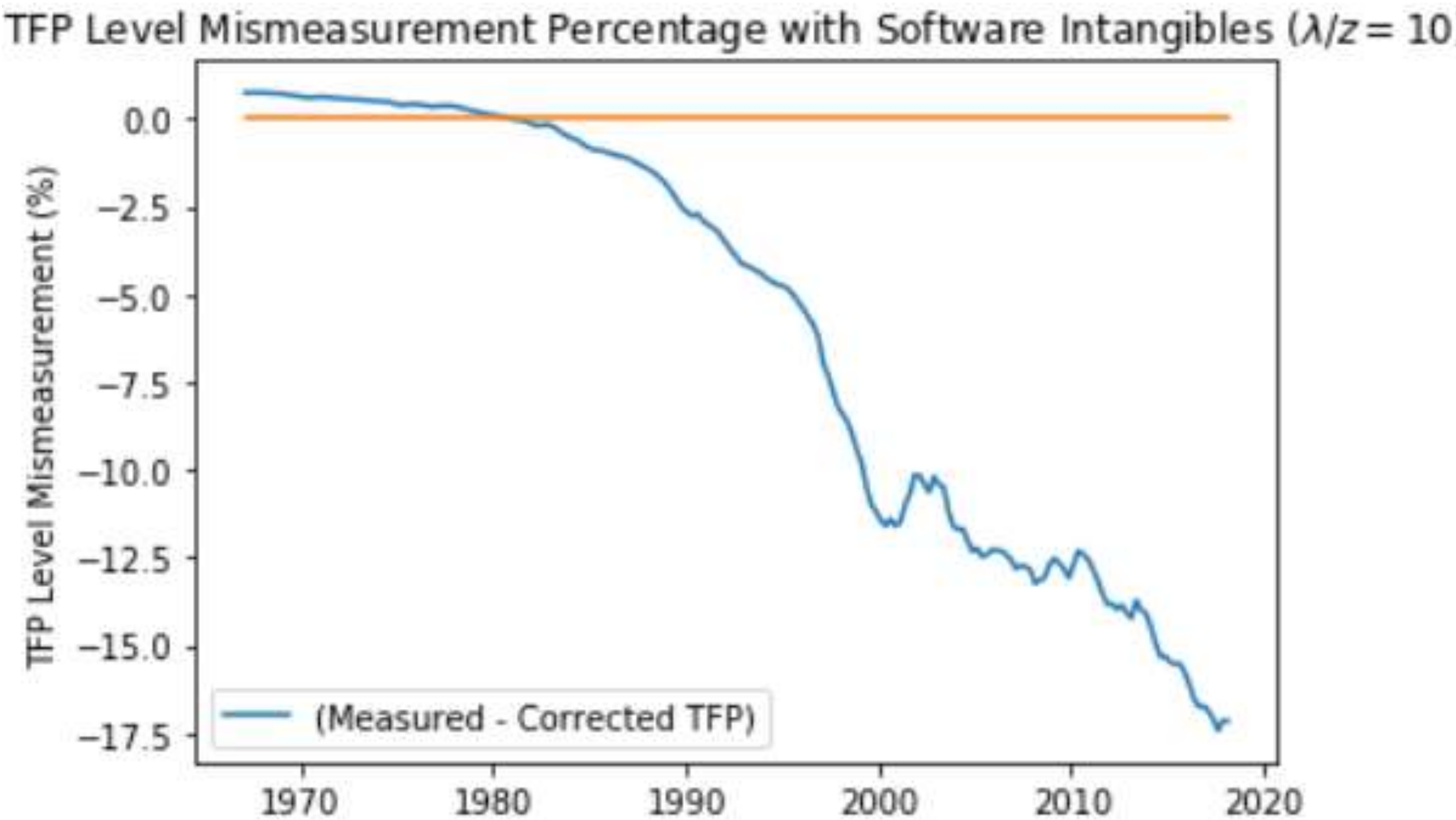
Adjusted TFP level is 4.4% higher in 2016 than measured

- Note this is the total growth measurement error accumulated over almost 50 years
- First half of *growth* J-curve has played out; hardware-related intangible accumulation has caused productivity growth overstatement (and brought levels back toward measured level) in past couple of years

TFP Growth Mismeasurement by Year: IT Software



TFP Accumulated Level Mismeasurement: IT Software



Adjusted TFP: IT Software

Implied mismeasurement due to software-related intangibles is much larger than for intangibles related to R&D or hardware

Adjusted TFP level is 17% higher in 2016 than measured

First half of growth J-curve might be played out, but less clear than for hardware

Does This Explain the Post-2004 Productivity Slowdown?

No; implied slowdown actually larger

A mismeasurement explanation for the slowdown doesn't require just mismeasurement; it requires a *change* in mismeasurement (in a particular direction and around 2004)

Period	Measured Annual TFP Growth (%)	Implied Annual TFP Growth (%)	Implied – Measured
1995-2004	1.63	2.53	0.90
2005-2017	0.40	0.85	0.45
Slowdown	1.23	1.68	0.45

Are AI-Related Intangibles Causing Mismeasurement?

Still very early in AI adoption, but fast investment growth

Generous estimate of U.S. AI investments in 2018 is $65-100B

If λ/z = $10, that's $650B to $1T in missing output in the form of intangible investments (about 3-5% of GDP)

Likely an upper bound, plus it doesn't account for (still likely small) countervailing input effect of AI-related intangibles

- And note AI investments before past couple of years were probably too small to have had aggregate effects

Conclusion

New technologies often require complementary intangible investments that can cause productivity mismeasurement

- First as missing output (productivity understatement)
- Later as missing input (productivity understatement)

This dynamic appears to have largely played out for R&D- and hardware-related intangibles

Still in play for software-related intangibles

AI-related intangibles might just now be creating enough mismeasurement to matter for aggregates